Application of New Detector Technology to PET

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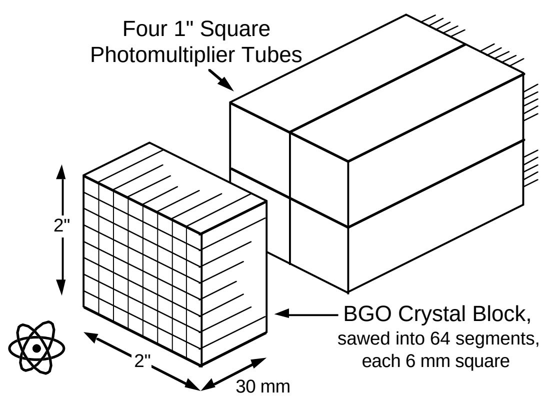
- Basic PET Detector Requirements
- New Photodetector Technologies
- PET Detector Modules based on New Photodetectors
- Possible Scintillator Improvements

Conventional Block Detector Design



$600 / in^2
$400 BGO
$200 PMT

Hit crystal identified by Anger Logic

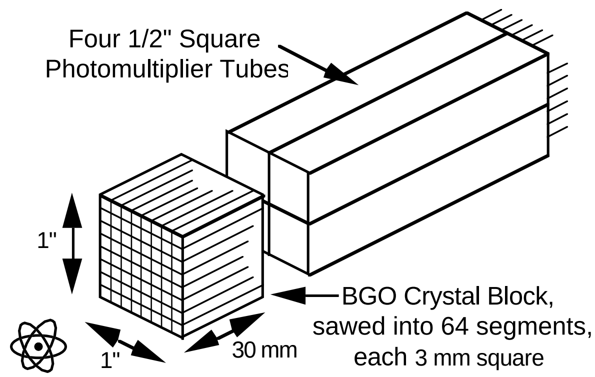
- **6 mm square crystals → 5 mm spatial resolution**
- **Detector block is 2 x 2 inches → 1.2 μs in^2 dead time**

PET Detector Requirements

Detect 511 keV Photons with

- **<5 mm spatial resolution**
- **<10 ns timing resolution**
- **<100 keV energy resolution**
- **“low” dead time (<1 µs in^2)**
- **“low” cost (<$600 / in^2)**

“Shrunk” Conventional Block Detector

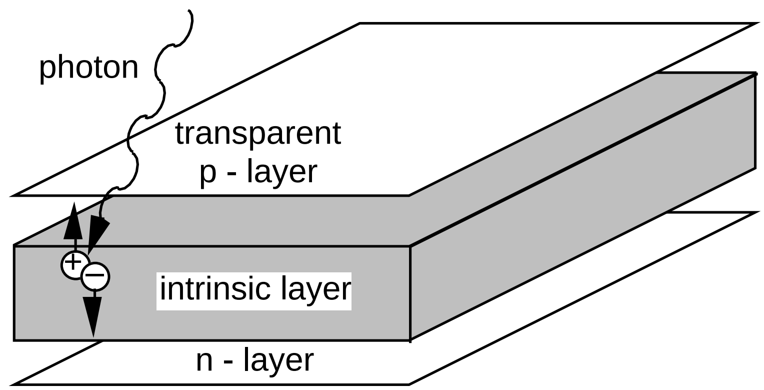


$1200 / in^2
$400 BGO
$800 PMT

Hit crystal identified by Anger Logic

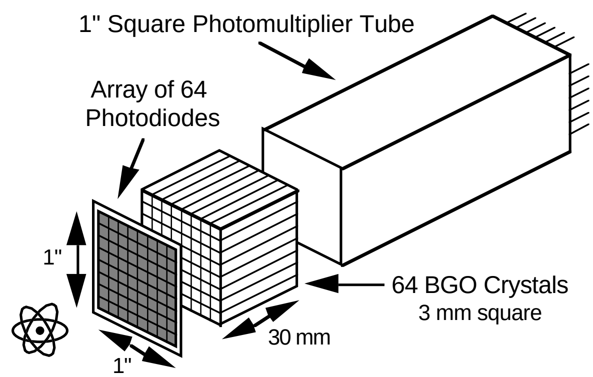
- **3 mm square crystals → 3 mm spatial resolution**
- **Detector block is 1 x 1 inches → 0.3 µs in^2 dead time**

Silicon PIN Photodiode



• Gain = 1
• Noise = 300 electrons fwhm
• $1 per 3x3 mm cell

PIN Photodiode Module Design

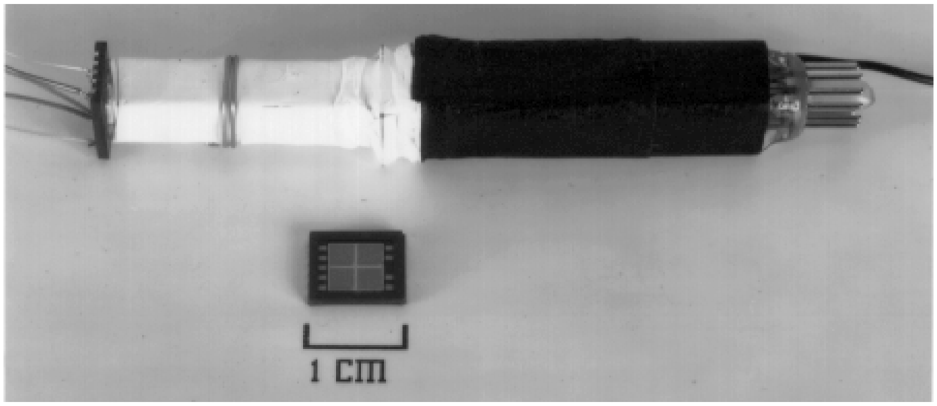


$700 / in^2
$400 BGO
$200 PMT
$100 PD

Hit crystal identified by photodiode array

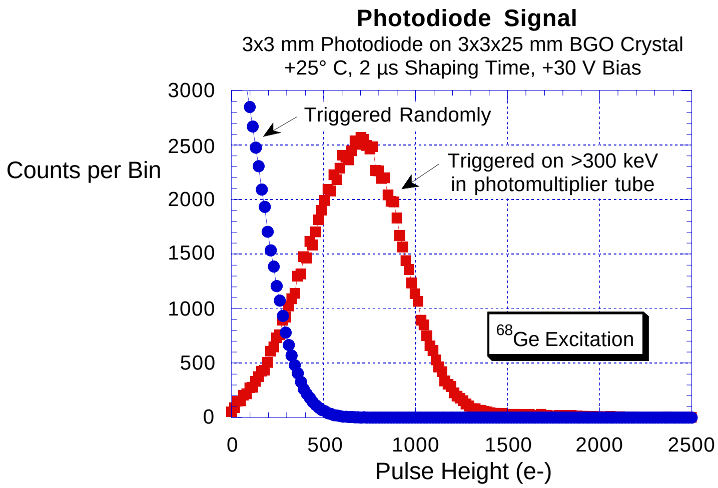
+ Economical, feasible with existing technology
– Signal to noise barely good enough - no margin for error

Prototype PIN Photodiode Module



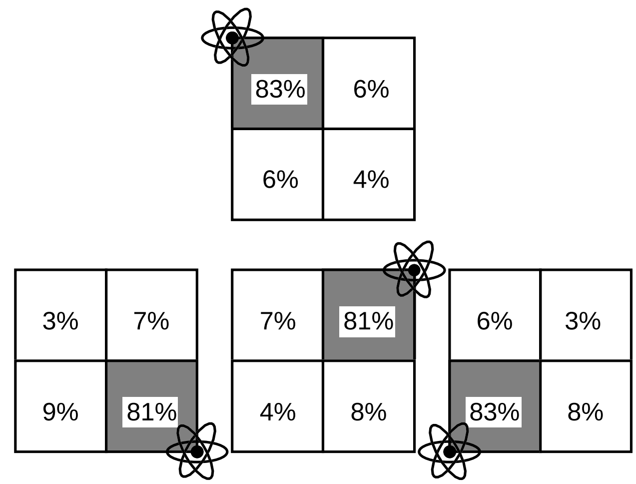
- One photomultiplier tube
- Four 3 x 3 x 30 mm BGO crystals
- Hit crystal identified with 2 x 2 photodiode array

Signal to Noise in PIN Photodiode



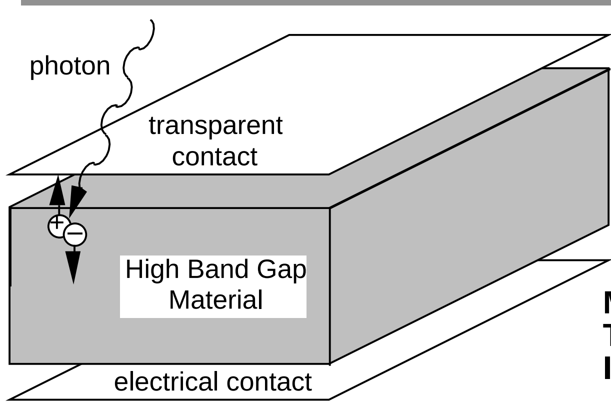
511 keV Signal is Well Separated from the Noise

Able to Identify Crystal of Interaction



Mis-identification dominated by Compton Scatter in BGO

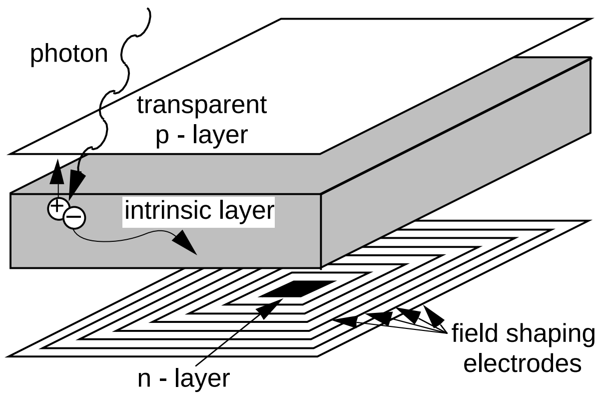
High Bandgap Material Photodiode



Mercuric Iodide
Thallium Bromide
Indium Iodide

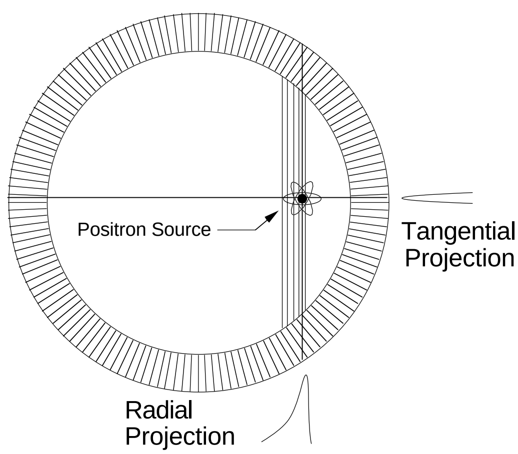
- **Gain = 1**
- **Noise = 100 electrons fwhm**
- **$2 per 3x3 mm cell?**

Silicon Drift Photodiode



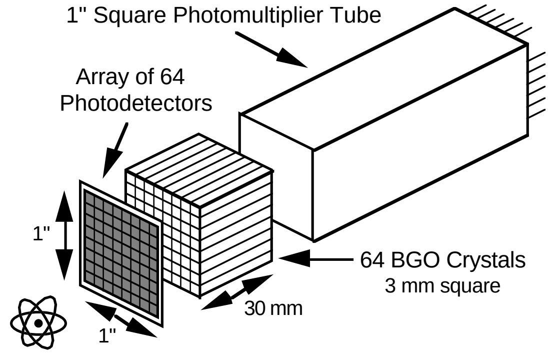
• Gain = 1
• Noise = 100 electrons fwhm
• $2 per 3x3 mm cell?

Radial Elongation Distortion in PET



• Mis-identification from penetration into adjacent crystal
• Can eliminate if depth of interaction in crystal measured

Depth of Interaction Measuring Module

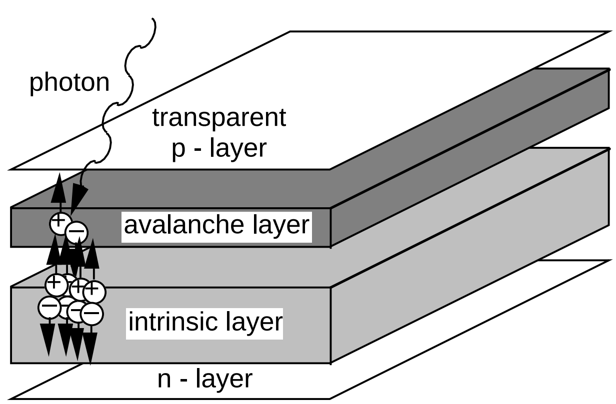


$800 / in^2
$400 BGO
$200 PMT
$200 PD

Depth of interaction measured using photodetector array (ratio of PMT signal to photodetector signal)

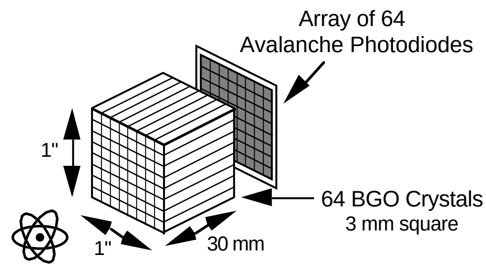
+ Good spatial resolution over *entire* field of view
– Signal to noise barely good enough - no margin for error

Avalanche Photodiode



• Gain = 200
• Noise low enough for timing
• $10 per 3x3 mm cell?

Avalanche Photodiode Module



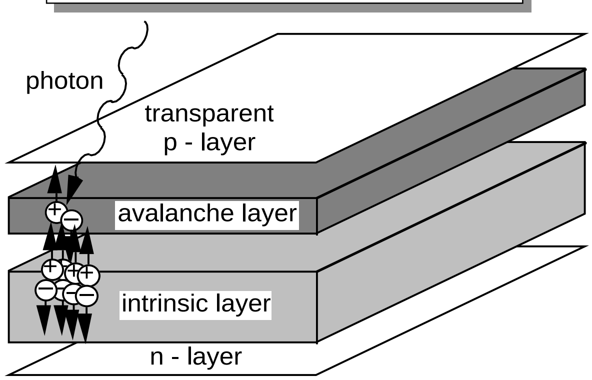
$1000 / in^2
$400 BGO
$600 APD

Timing measured by avalanche photodiode array

+ Electronics & packaging simpler
– Very temperature sensitive, timing barely good enough

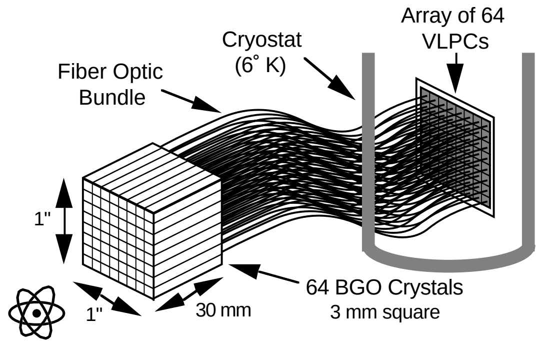
VLPC
(Visible Light Photon Counter)

6° K



- **Gain = 50,000**
- **Noise easily low enough for timing**
- **$35 per 3x3 mm cell?**

VLPC Module



$2600 / in^2
$400 BGO
$2200 VLPC

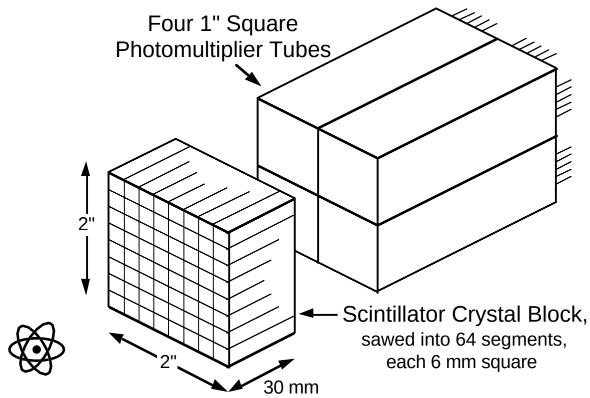
Fiber optic bundle brings light from BGO to VLPC

+ Higher gain, better timing
– Light loss in fiber optics, VLPC operates at 6˚ K

What Would You Do With a Better Scintillator?

- **Shorter Decay Time**
- **Higher Stopping Power**
- **Higher Light Output**

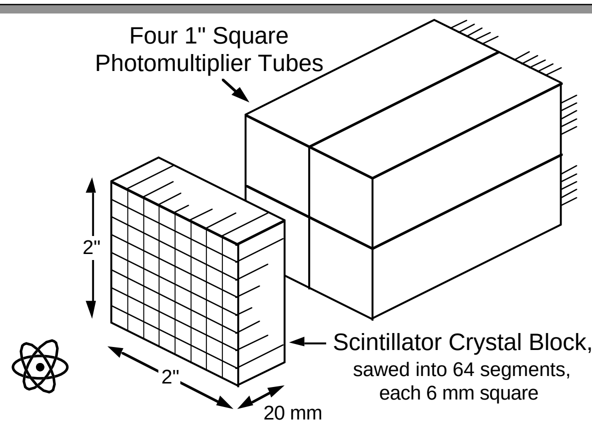
Shorter Decay Time Scintillator



Conventional configuration, but better timing resolution

• Less dead time, better image contrast (time of flight)
• Same spatial resolution (5 mm)

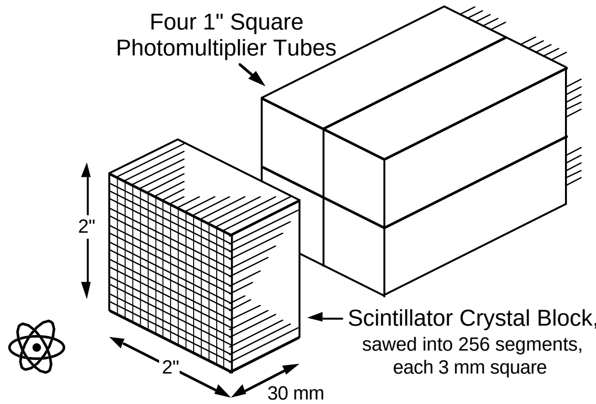
Higher Stopping Power Scintillator



Conventional configuration, but with thinner block

• Same spatial resolution (5 mm), but over larger field of view
• Same dead time, better image contrast

Higher Light Output Scintillator



Conventional configuration, but with smaller crystals

- **Better spatial resolution (3 mm)**
- **Same dead time**

Improved Scintillators ARE Possible

Example: LSO (Lutetium Orthosilicate)

- **Light Output 5x More than BGO**
- **Decay Time 7x Faster than BGO**
- **Stopping Power Same as BGO**
- **Price 10x More than BGO**

Conclusions

Advanced Photodetectors can Improve PET Detector:
- Spatial Resolution
- Dead Time
- Cost

New Scintillators can Improve All Aspects of Detector Performance

Acknowledgements

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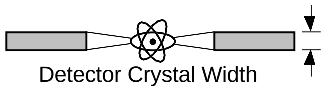
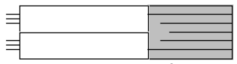
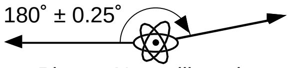
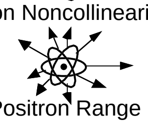
National Cancer Institute, grant No. R01-CA48002
National Institute of Neurological Disorders, grant No. R01-NS29655.

Contributions to Spatial Resolution

Factor	Shape	FWHM
 d Detector Crystal Width		d/2
 Anger Logic		0 (individual coupling) 2.2 mm (Anger logic)* *empirically determined from published data
180° ± 0.25°  Photon Noncollinearity		1.3 mm (head) 2.1 mm (heart)
 Positron Range		0.5 mm (^{18}F) 4.5 mm (^{82}Rb)
Reconstruction Algorithm	multiplicative factor	1.25 (in-plane) 1.0 (axial)